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PREEMPHASIS DETERMINATION FOR AN S-BAND  
CONSTANT BANDWIDTH FM/FM STATION

By G. R. Wallace  
Astrionics Laboratory

W. E. Salter  
Sperry Rand Corporation

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16. ABSTRACT <p>Preemphasis schedules are given for 11 constant-bandwidth FM subcarriers modulating an S-band transmitter at three receiver signal-to-noise ratios (i.e., 9, 15, and 25 dB). The criterion for establishing these preemphasis curves is the achievement, at various receiver intermediate frequency signal-to-noise ratios, of equal receiver output signal-to-noise ratios for all channels. It is realized that these curves may not be the optimum preemphasis curves based on overall efficiency or maximum utilization of the allotted spectrum, but they are near-optimum for data with channels which require equal output signal-to-noise ratios, such as spectral densities.</p> <p>The empirically derived results are compared with a simplified, analytically derived schedule and the primary differences are explained. The S-band preemphasis schedule differs from the lower frequency VHF case. Since most proportional bandwidth and constant bandwidth systems use ground-based recorders and some use flight recorders (as the Saturn systems did on VHF proportional bandwidth telemetry), the effects of these recorders are discussed and a modified preemphasis schedule is presented showing the results of this study phase.</p> <p>NOTE: The activity reported here is a portion of the effort under RTOP 150-22-03, Mission Spacecraft Compatibility with Telemetry Data Relay Satellite System, and was accomplished at the Astrionics Laboratory.</p>			
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## PREEMPHASIS DETERMINATION FOR AN S-BAND CONSTANT BANDWIDTH FM/FM STATION

### INTRODUCTION

The intention of using one of the preemphasis curves outlined in this report with a telemetry system is to ensure that in a decreasing signal-to-noise (S/N) ratio situation the user can have approximately equal output S/N ratios for all channels while operating at one of three preselected receiver intermediate frequency (IF) S/N ratios (i.e., 9, 15, and 25 dB). These three figures were selected to allow the user to relate to three frequently mentioned system figures. The 9-dB figure is often mentioned as a receiver threshold figure and in this study is the highest figure at which the receiver noise density curve first departed from the characteristic triangular noise spectrum. The 15-dB figure was selected because the discriminator click phenomena start to occur in this vicinity. The 25-dB figure was selected because it is often the desired design minimum IF S/N figure on telemetry systems. It is realized that these may not represent the optimum preemphasis curves based on overall efficiency or maximum utilization of the allotted spectrum, but it may well be a reasonable criterion for data such as spectral densities.

In the United States, telemetry users are limited to three frequency bands: 216 to 260 MHz, 1435 to 1535 MHz, and 2200 to 2300 MHz. Because of projected reallocations by the Federal Communications Commission (FCC), the future telemetry bands will be concentrated in the UHF bands at 1500 and 2200 MHz.

Recently, a study was conducted at MSFC to determine some of the problems associated with the conversion of an existing constant-bandwidth (CBW) FM/FM system operating in the VHF band to the UHF band at 2200 MHz (commonly referred to as S-band). This conversion does not present the major problems as it may appear at first glance. Primarily, changes are required in the equipment used in the radiofrequency (RF) link, while many of the same subcarrier oscillators (SCOs), mixer amplifiers, and frequency discriminators can be used.

In comparing transmission in the VHF band with S-band, one important difference is noted, i. e., more transmitter bandwidth is available for S-band; since it is available, using only part of it is normally not required, even if satisfactory performance could be obtained. The additional bandwidth can be utilized by increasing the FM transmitter deviation that is accomplished by an increase in the output voltage level of one or more of the SCOs, thus altering the preemphasis schedule. The development of this report provides the results of recent endeavors in determining the optimum preemphasis schedules for the system shown in Figure 1 for a criterion based on equal output S/N ratios on all channels for specified receiver IF S/N ratios.

Initially, the results of a simplified analytical approach are outlined, but since in actual practice many factors, such as the effects of intermodulation, must be considered which make an analytical treatment impractical, the main endeavor of this study is decidedly empirically oriented. The analytical and empirical results are compared and the primary differences are discussed. Since most proportional bandwidth (PBW) and CBW systems use ground-based tape recorders and some use flight recorders (as the Saturn systems did for VHF PBW telemetry), the effects of these recorders are discussed, and a modified preemphasis schedule is presented showing the results of this study phase.

The static situation with unmodulated SCOs was selected to give what appears to be the highest power intermodulation products and thus the largest effect on the S/N ratios. However, one may believe that this is too much a worst-case condition and that data will vary and thereby reduce the intermodulation products significantly. For this reason, additional tests are performed by applying uncorrelated, band-limited Gaussian noise to all data channels.

## SIMPLIFIED ANALYTICAL DERIVATION OF PREEMPHASIS SCHEDULE

One may analytically construct a preemphasis schedule using an approach similar to that taken by Campbell [1], assuming that only the triangular noise spectrum is to be compensated for and, further, that the receiver noise input has a relatively small, flat spectral density shape. As Campbell explains, one needs only to consider two SCOs at a time to establish the relative values for all channels. The basic frequency versus voltage relationship is simply explained almost without elaboration in Figure 2 (the notations were selected to be the same as the referenced article for ease in cross referencing). The basic idea is to establish SCO

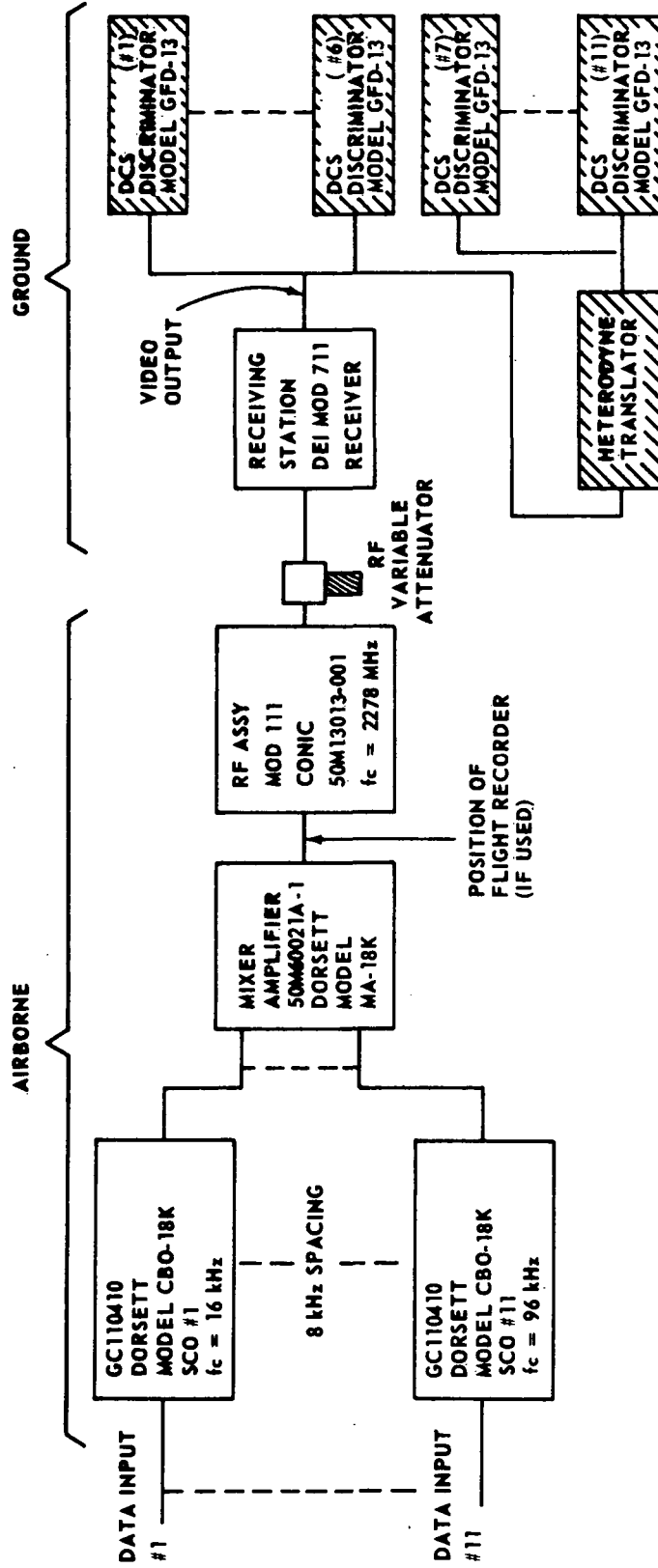


Figure 1. CBW FM/FM system.

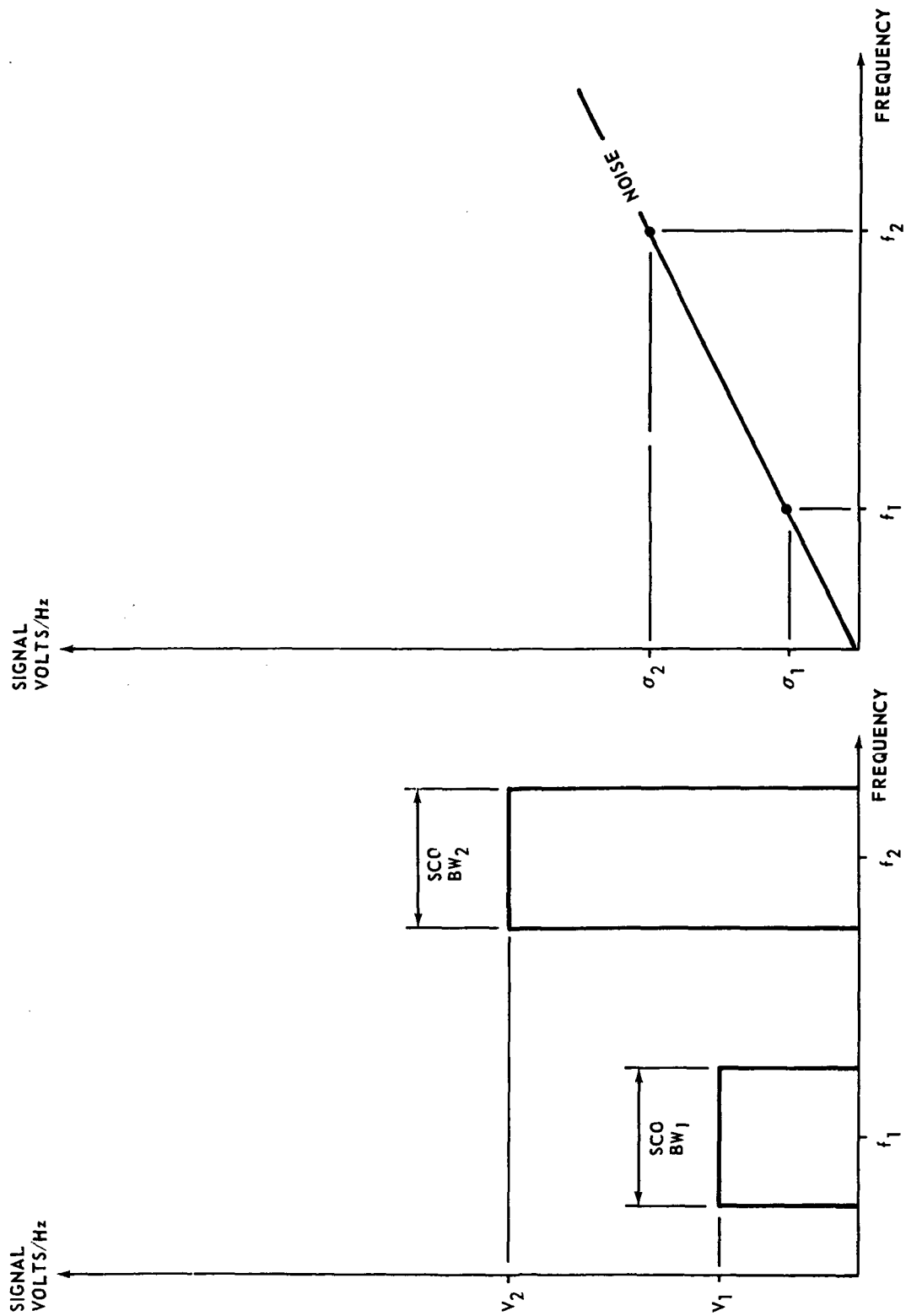


Figure 2. Receiver output showing noise and SCOs' bands.



levels such that the S/N ratios of all channels are equal (i. e.,  $S_i/N_i = S_j/N_j$  where i and j represent different channel numbers). The total noise power, N, on a channel is given by the product of noise voltage density for that channel and the channel bandwidth, or  $N = \delta \times BW$ . Since one wishes to establish a system with all channels having equal S/N ratios, select any two channels i and j and set  $S_i/N_i = S_j/N_j$ . Substitute the appropriate values of  $S_i$  and  $N_i$  ( $S_i = V_i^2$ , where  $V_i$  = signal voltage and  $N_i = \delta BW_i$ ), and similarly for  $S_j$  and  $N_j$ . The result is  $V_i = V_j (f_i/f_j)^{3/2}$  for a PBW system and  $V_i = V_j (f_i/f_j) = f_i k$  for a CBW system, where again  $V_i$  and  $V_j$  signify the signal voltages of the two SCOs.

The results are precisely what one may expect. Figure 3 shows the familiar 3/2 curve for the PBW system and the straight line for the CBW system. For a more thorough treatment of these types of calculations, see Reference 1.

As a final analytical note to establish a foundation for further comparisons with empirical data, consider 11 CBW FM subcarriers modulating an S-band transmitter having a deviation sensitivity of 205 kHz/V. Assuming that 400-mV rms is assigned to the highest frequency channel (96 kHz) because of RF spectrum limitations, one gets the straight line preemphasis curve outlined in Figure 4.

## SYSTEM DESCRIPTION

An analytical solution is a reasonable "first" endeavor to achieve an optimum preemphasis curve; however, as in most analytical treatments, the system conditions are very restricted and only two simple assumptions are made; i. e., flat noise into the receiver and triangular noise out of the receiver increasing at a rate of 6 dB/octave. When other assumptions consider items such as intermodulation effects attributed to system nonlinearities and non-triangular RF noise spectrum for the receiver at low IF S/N ratios, the analytical treatment becomes more involved. Rather than attempting to design an accurate model, the balance of this study will be entirely empirical.

A block diagram of the 11-channel CBW system used in the experiment is shown in Figure 1. The baseband format conforms to the Inter-Range Instrumentation Group (IRIG) specifications [ 2] for CBW subcarriers having 2-kHz peak deviations. The SCOs were Dorsett Model CBO-18Ks with full bandwidth deviations of  $\pm 2$  kHz. The Dorsett Model MA-18K mixer amplifier

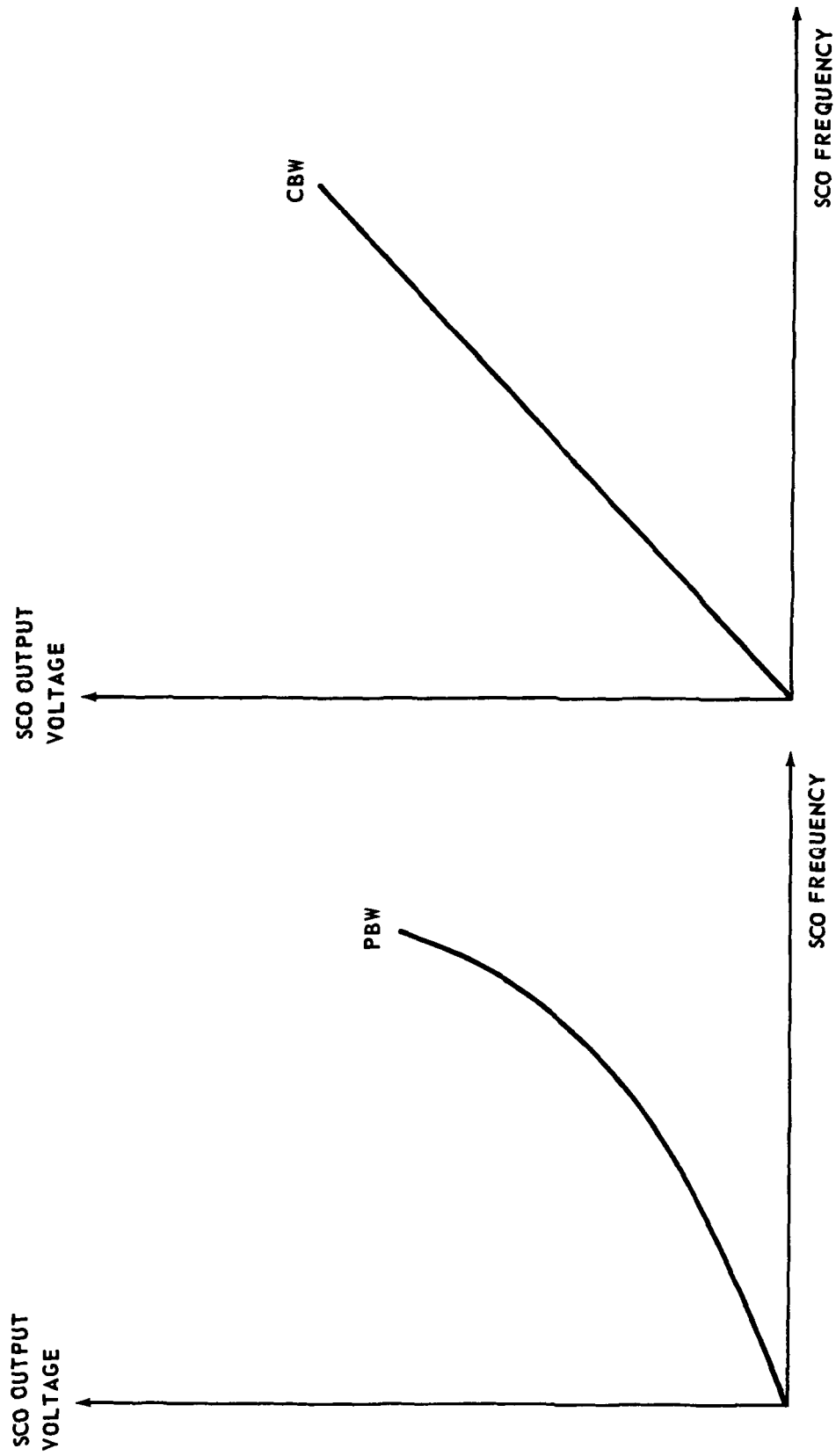


Figure 3. Preemphasis curves for PBW and CBW systems — simplified analytical basis.

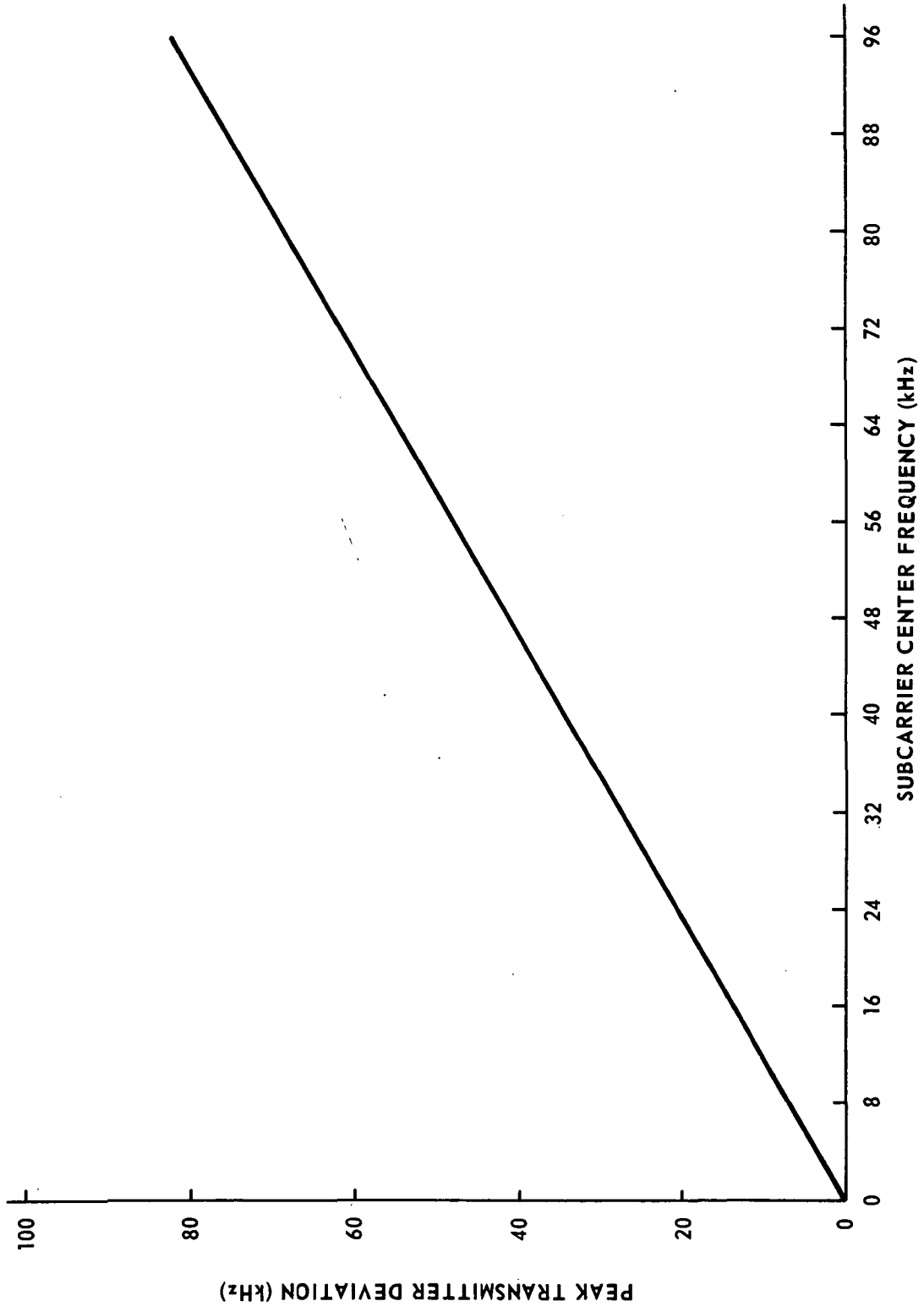


Figure 4. Analytically derived preemphasis curve for an 11-channel CBW system.

sums the individual SCO outputs to form the composite multiplex which deviates the transmitter. For preemphasis adjustments, the output level control on each affected SCO is used, while the gain control on the mixer amplifier is used for adjustment of the total multiplex level.

The output of the Conic UHF transmitter, with carrier frequency centered at 2278 MHz, is hard-wired to the receiver through a variable attenuator that is used for selection of the desired receiver IF carrier-to-noise ratio. The Defense Electronics Model TR-711 receiver is operated with a 1.5-MHz IF filter and a 2-MHz video filter. The receiver output feeds into a bank of frequency discriminators. Channels one through six are demodulated directly while the remaining channels are heterodyned with a 120-kHz signal that places the difference-frequency band in the positions of channels two through six. The appropriate bandpass selection filters and lowpass output filters are connected into the Data Control System (DCS), Type GFD-13, frequency discriminators to demodulate the subcarriers. The cross-hatched blocks of Figure 1 are not needed, but were included to provide an alternate approach to such system testing.

## PREEMPHASIS EVALUATION

Generally, the preemphasis is adjusted to provide all channels in the multiplex with identical S/N performance when the receiver is operating near threshold. In addition, the total multiplex level is adjusted such that the radiated spectrum approaches but does not exceed the limit specified by Reference 2.

Since the spectral shape of the receiver output noise is a primary factor in establishing a preemphasis schedule, careful attention must be given to determining the receiver threshold. The output noise spectrum for the DEI TR-711 receiver is shown in Figure 5 for various selections of IF S/N ratios. From its normal triangular shape of 6 dB/octave, the output noise spectrum has a tendency to become flat on the low frequency end for the low signal levels. For values of IF S/N ratios less than 9 dB, the receiver noise becomes excessive and the transmission link is too poor to be of further use.

The preemphasis schedule obtained for the system described is shown in Figure 6. Briefly, the procedure used was to operate the receiver at the IF carrier-to-noise ratio of 9 dB, while adjusting the individual unmodulated SCO outputs to produce identical subcarrier-to-noise ratios at the receiver video output. Measuring the subcarrier-to-noise ratio at the video

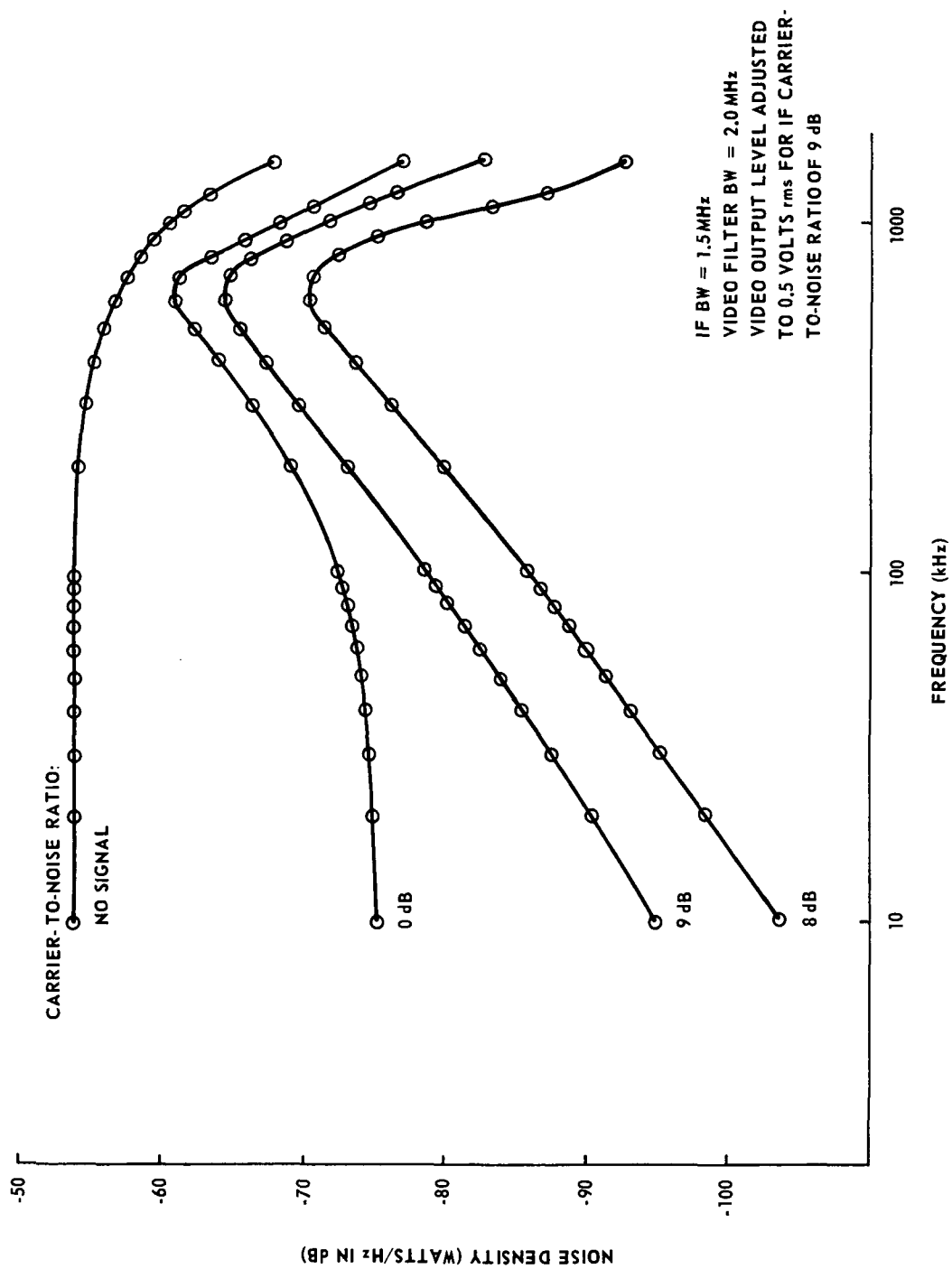


Figure 5. Receiver noise density (Defense Electronics Model TR-711).

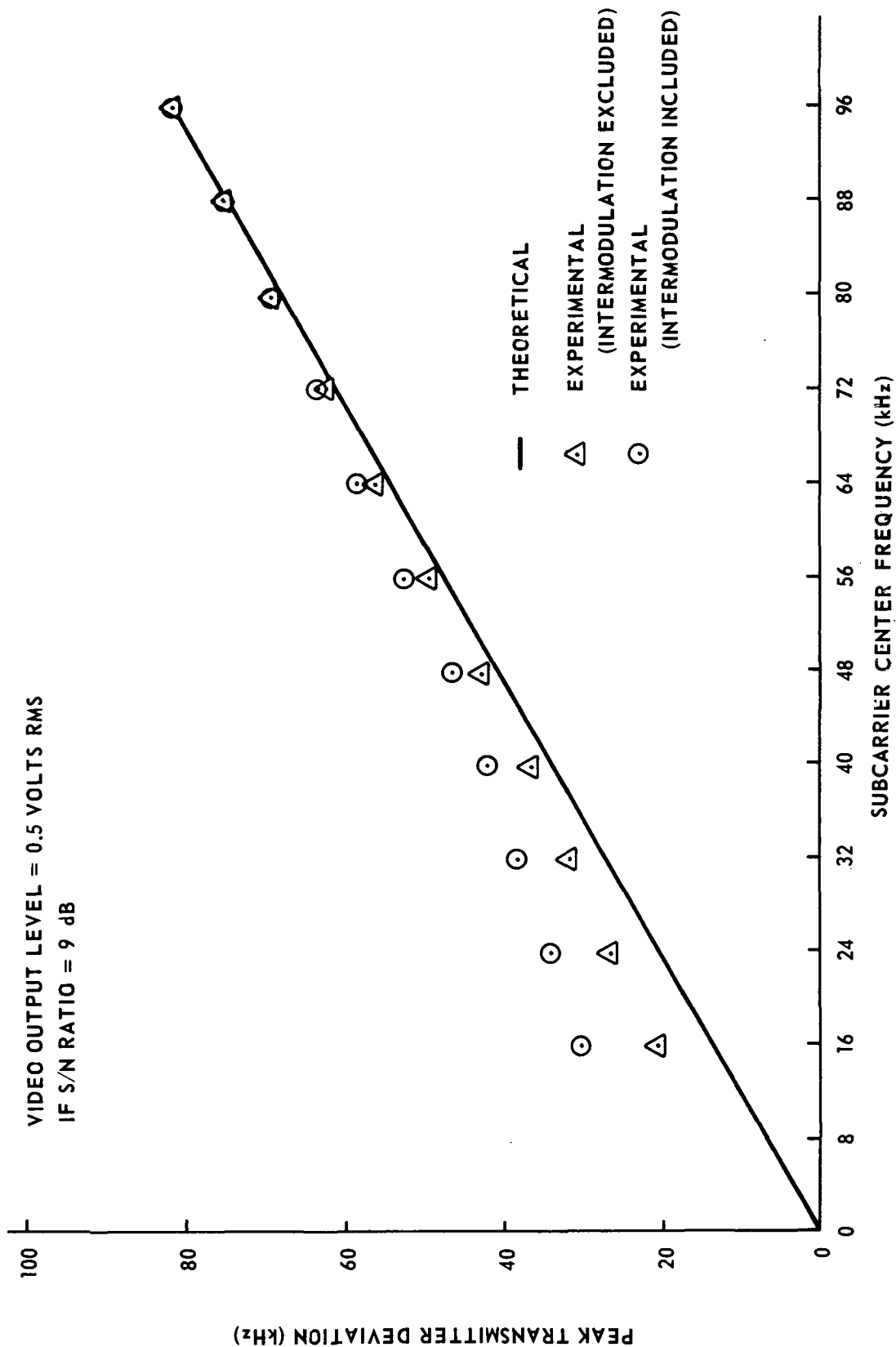


Figure 6. Preemphasis schedule for CBW multiplex, channels 1 through 11.

output deviated from the well-established practice of making the measurement at the output of the bandpass input filters of the frequency discriminators, but is more desirable in that the results obtained are independent of any particular bank of ground discriminators.

This technique establishes only the relative levels of the individual SCOs, while the absolute level (i.e., the actual transmitter deviation allotted to each channel) depends upon the bandwidth limitations placed on the total RF spectrum. The gain control on the mixer amplifier can be used to adjust the total multiplex level to achieve the desired spectrum bandwidth. This is permissible since small variations in the total multiplex level do not alter the relative relationships of the individual subcarrier-to-noise ratios.

The measured preemphasis data are compared with the simplified analytical solution (see straight line) in Figure 6; differences are noticeable, especially in the low-frequency SCOs. In both the experimental "middle" taper and the straight-line approximation, the effects of intermodulation are excluded. The difference between the two curves results from the deviation in practice from the triangular-shaped noise spectrum which characterizes the ideal receiver.

The additional noise contributed by intermodulation causes a further shift in the preemphasis taper as depicted by the topmost curve in the figure. Again, the change is most significant on the low-frequency SCOs. This represents a worst-case condition for this type of system, since all SCOs are at their center frequencies and the high-amplitude difference frequencies resulting from intermodulation lie directly in the center of the various data channels.

If it is determined that inadequate performance is obtained because of the 9-dB IF S/N ratio, other preemphasis curves can be obtained for higher S/N ratios by using the same procedure followed in this report. Results are shown in Figure 7 for various selections of IF S/N ratios. Note that higher S/N ratios result in greater deviations from the theoretical curve, the cause being the greater relative effects of intermodulation products on the system noise.

As mentioned previously, the preemphasis curves were determined for the conditions where all data channels were unmodulated. To verify that this condition was not completely unrealistic compared with actual data, tests were conducted using uncorrelated, band-limited Gaussian noise as data inputs to all SCOs. The results of these tests showed little measurable change from those of the unmodulated condition.

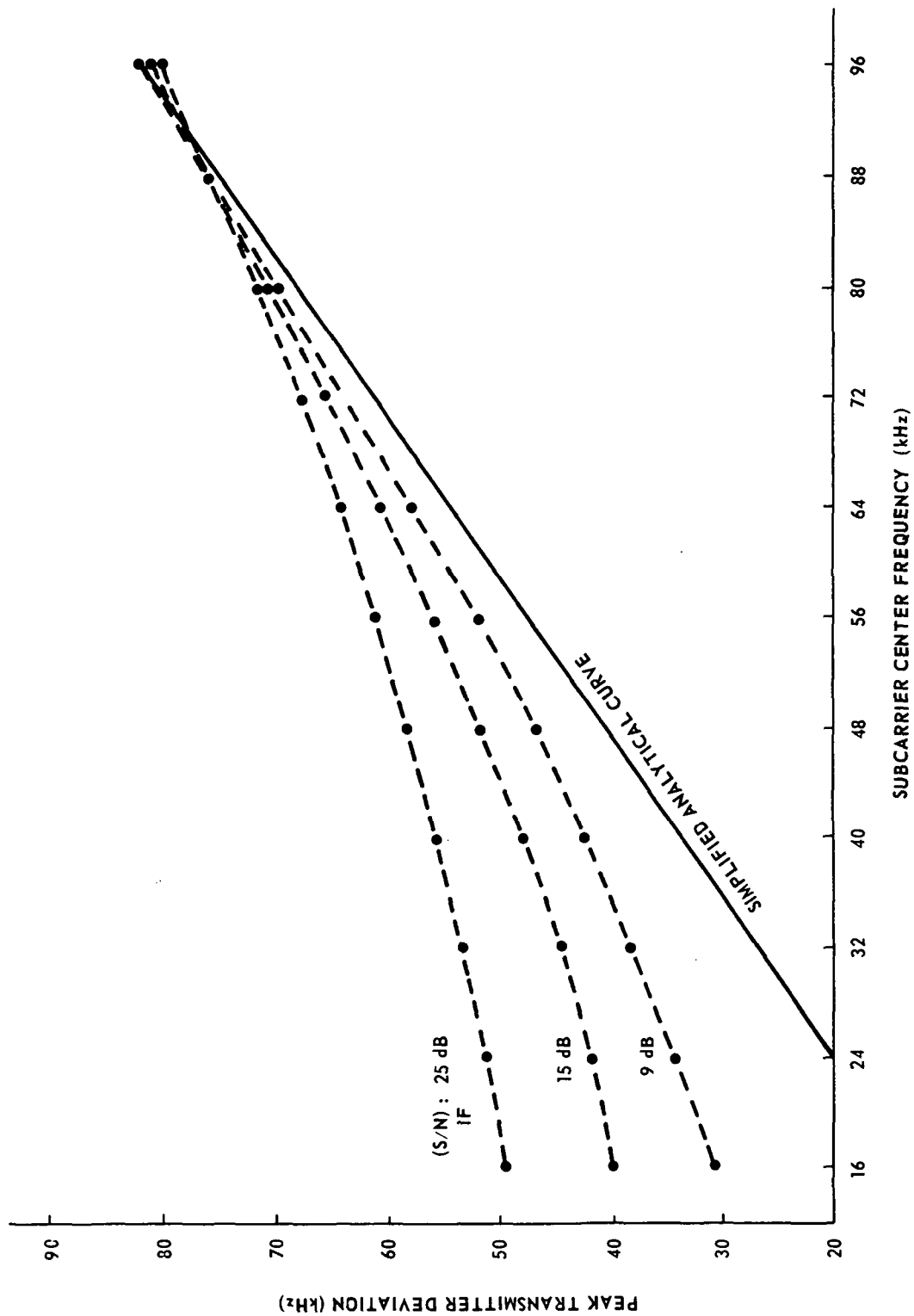


Figure 7. Preemphasis curves for various S/N ratios and simplified analytical curve.



## TAPE RECORDER EFFECT ON PREAMPHASIS

In telemetering on Saturn flights, on-board analog recorders are commonly used to record the system outputs during periods of ground station signal loss (at separation of stages). Ground-based tape recorders for either predetection recording or direct recording of the signal at the receiving station are commonly used. If recorders are included in the telemetry link and if the individual subcarrier-to-noise ratios undergo a significant change, then modification of the preemphasis schedule is necessary.

When a ground-based tape recorder is used to record and reproduce the baseband signal produced from the receiver video output, any noise added by the recorder affects the subcarrier-to-noise ratio in each channel. Should the noise power spectral density of the recorder differ in shape from that of the receiver, then more noise will be added in one portion of the baseband than the other. Of course, if the recorder noise is very low relative to the total system noise, the question of modifying the system preemphasis would be academic. However, referring to Figure 8, one sees that this is not always the case. The noise level of the recorder is only about 6 dB below the receiver noise at the position of the lowest frequency channel (16 kHz). This causes approximately a 1-dB increase in the overall system noise on this channel while the higher channels in the baseband are not appreciably affected. Thus, the addition of the tape recorder in the link necessitates a change in the system preemphasis schedule as shown in Figure 9. It should be noted, however, that if the video output level of the receiver had been made larger (about 1 V), then the effects of the tape recorder noise would be negligible. Since the video output level of 0.5-V rms used in the test was sufficient to ensure proper operation of the frequency discriminators, the subcarrier noise levels were not high enough to be relatively independent of the tape recorder noise. Thus, if the receiver video output is properly adjusted before recording, the effects of the tape recorder noise on the system preemphasis can be reduced.

The effect of predetection recording was also investigated. Predetection record/playback (converter) units can significantly alter the noise characteristics of the link and, therefore, must be considered in any preemphasis adjustments. However, in the tests conducted on different units, the noise added was so high and the variances among different units were so great that the results are not reported here. Individual tests on specified systems should be conducted to ensure proper and expected operation.

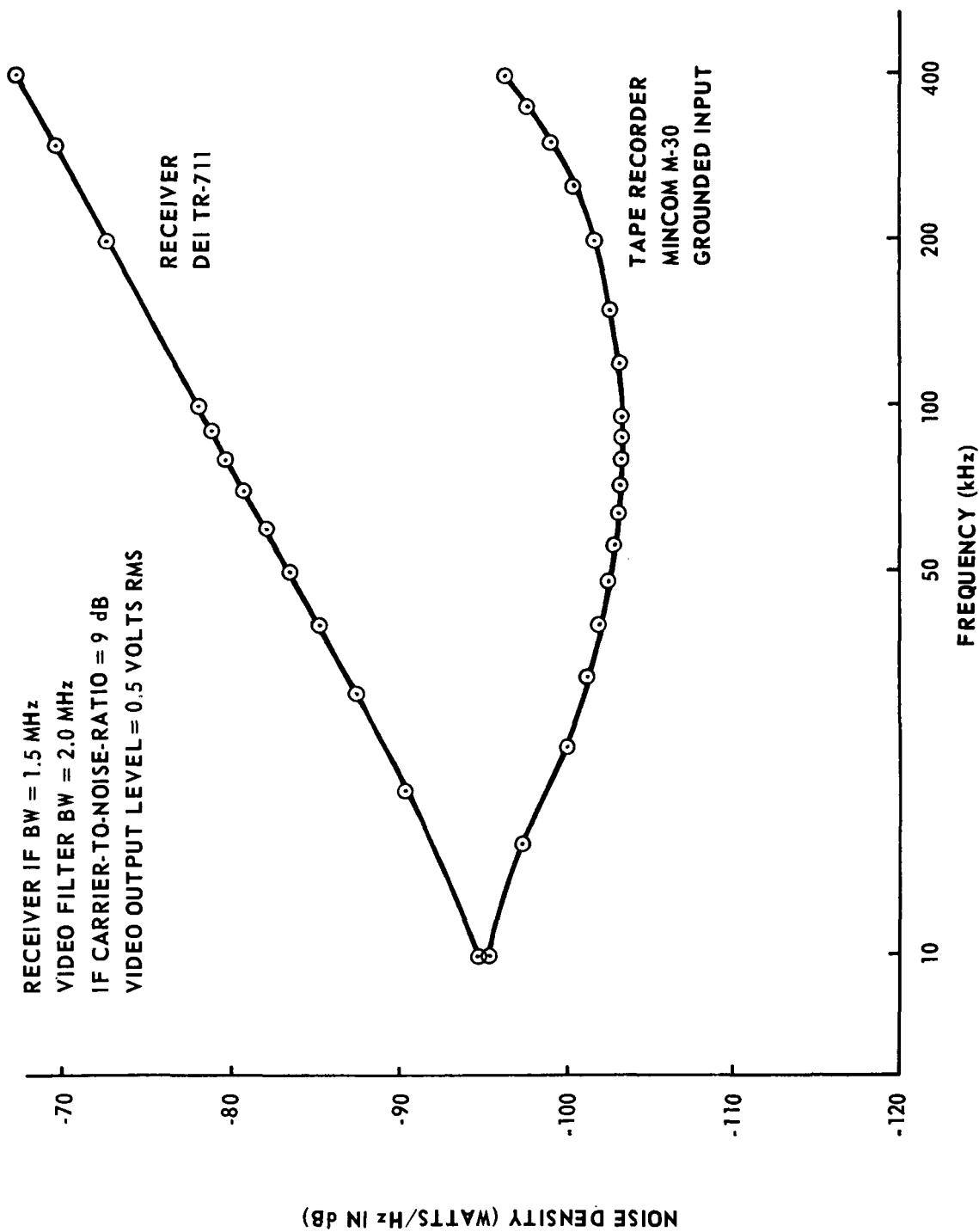


Figure 8. A comparison of receiver output noise and tape recorder noise.

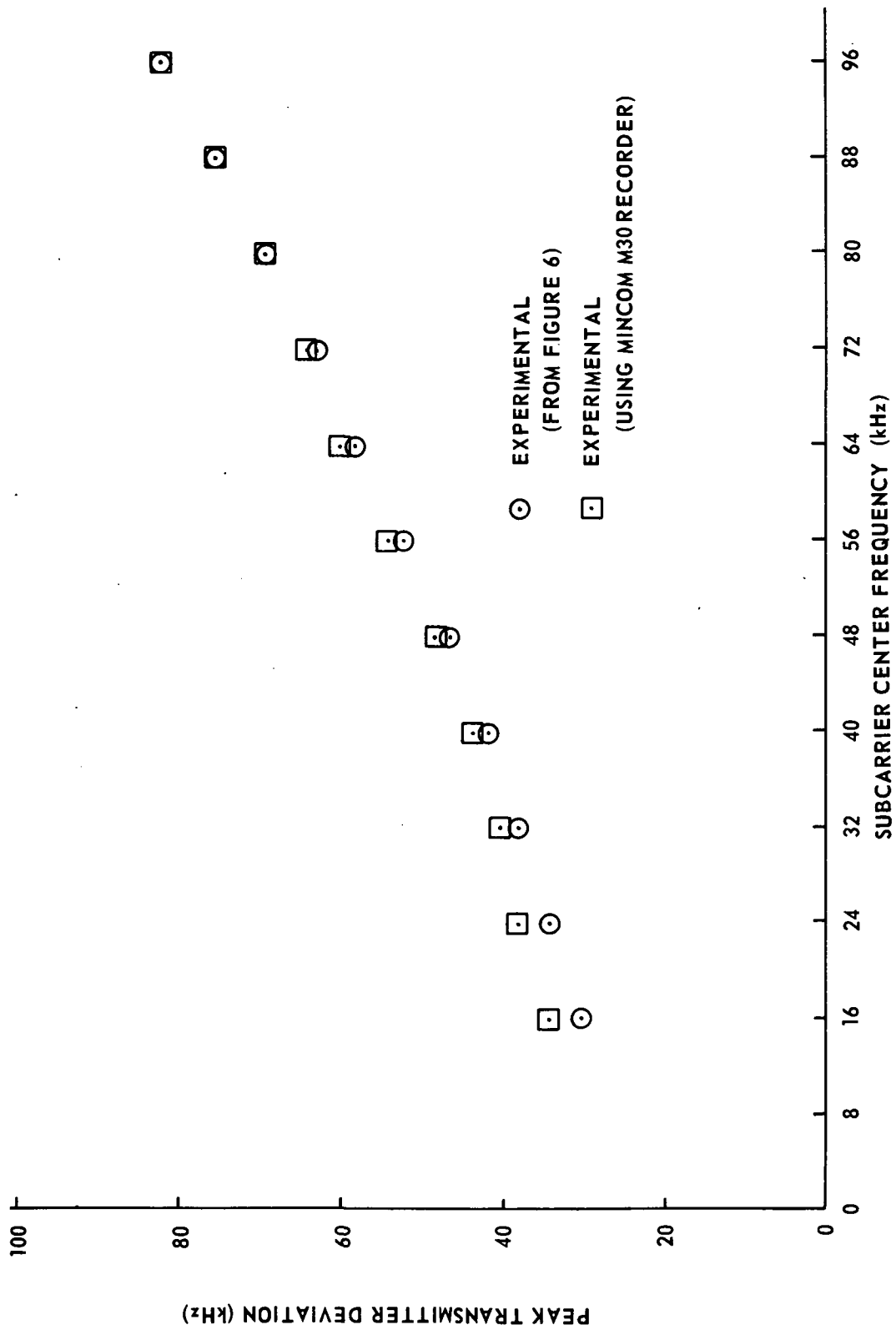


Figure 9. Test data showing the effect of a tape recorder on preemphasis.

On investigation of several short-time reel-to-reel machines used for on-board recording, it was found that all of these recorders affected the system preemphasis. The noise contributed by these recorders exerts a distinct and measurable amount of influence on the link, while intermodulation products generated by the recorder, like similar products generated elsewhere in the system, also affect baseband noise levels. In one typical machine, a crystal-controlled 120-kHz signal, superimposed on the tape for frequency reference during playback, is harmonically related to the baseband center frequencies. Thus, different frequency components are created which fall exactly in the center of each of the data channels (with the exception of the channel centered at 16 kHz), causing additional intermodulation distortion.

## CONCLUSIONS

The preemphasis for a CBW FM/FM system designed to operate at the VHF telemetry band must be altered to give optimum performance at S-band because of the increased transmitter bandwidth availability. While an analytical solution gives a reasonable approximation of the system preemphasis, it is far from optimum. The reasons are primarily two-fold: (1) the analytical solution assumes ideal receiver noise characteristics, which in actual practice is not the case, especially near receiver threshold, and (2) noise resulting from intermodulation products is not negligible as is assumed in the analytical case. Generally, the actual preemphasis curve assumes a somewhat flatter slope than the theoretical channels. No significant changes were evident between the preemphasis schedules determined using worst-case unmodulated subcarriers and band-limited noise as data. Finally, the addition of tape recorders, either ground-based or flight type, was found to cause varying effects on the preemphasis. If direct recording is used, judicious selection of recording video gain negates the adverse effects of the tape recorder. If predetection recording is used, systems should be tailored to include the effects of both the recorder and the record/playback converter units that will be used.

## REFERENCES

1. Campbell, Allan: Preemphasis for Constant Bandwidth FM Subcarrier Oscillators for FM and PM Transmitters. Proceeding of the ITC, pp. 232-240, 1970.
2. Telemetry Standards. IRIG 106-109, Revised February 1969.

# APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.



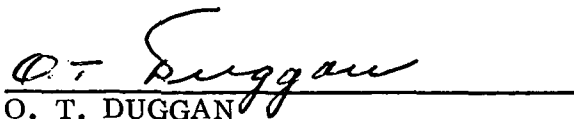
W. B. THRELKELD

Chief, Telemetry, Test, and Analysis Section



ROBERT EICHELBERGER

Chief, Telemetry and Data Technology Branch



O. T. DUGGAN

Chief, Instrumentation and Communication Division



F. B. MOORE

Director, Astrionics Laboratory